Appendix M: Climate impacts and adaptation actions for the Okanagan-Kettle region

Figure M.1. A view of the Okanagan Valley.

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, a vegetation system, and a region chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the Okanagan-Kettle region.

The Okanagan-Kettle region straddles the Washington-British Columbia border from the Coast Range and Cascade Mountains (to the west) to the Monashee Mountains and Kettle Range (to the east) (Fig. M.2).[2] This region features relatively well-connected montane habitats found at higher elevations, and highly fragmented shrub-steppe habitats found at lower elevations, where development and highways present significant barriers to wildlife movement.[2] Notable movement barriers in the region include Highways 3A and 97, which run north-south along the length of the Okanagan Valley, creating a significant barrier to east-west movement. In the British Columbia section of the Okanagan Valley, east-west connectivity is also extremely constrained by a series of lakes interspersed with small towns and development (Appendix M.1).

Future climate change may present additional challenges and needs for habitat connectivity in the Okanagan-Kettle region.[3-4] First, climate change may impact core habitat areas and dispersal corridors in ways that may make them more or less permeable to wildlife movement. Second, existing core habitat areas and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in species distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions for connectivity conservation under climate change. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for wildlife habitat connectivity in the Okanagan-Kettle region (but see Transboundary Connectivity Group (2016)[2]). To address these needs, we describe here a novel effort to identify and address potential climate impacts on wildlife habitat connectivity in the Okanagan-Kettle region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

Project partners focused on identifying potential climate impacts on the heavily fragmented valley floors that present major barriers to wildlife movement within the Okanagan-Kettle region (Fig. M.2), with an emphasis on habitat connectivity priority areas previously identified for the region (Appendix M.1). To

[i] This report is Appendix M of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

do this, project partners evaluated projected changes in vegetation and relevant climatic variables for valley floors and priority habitat connectivity areas (Appendix M.1). Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, project partners relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Transboundary Connectivity Group and the Washington Connected Landscapes Project,[2,6] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[7] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[8] and models of projected range shifts and vegetation change from the Pacific Northwest Climate Change Vulnerability Assessment.[9]

Key impacts on habitat connectivity for the Okanagan-Kettle region identified through this approach include changes in vegetation, changes in hydrology, changes in disturbance regimes, and changes in invasive species.

Changes in vegetation

Changes in the distribution and quality of vegetation communities in the transboundary region are likely to affect wildlife habitat connectivity. Three types of models are available that estimate future changes in vegetation for the Okanagan-Kettle region: 1) climatic niche model projections for big sagebrush, *Artemisia tridentata* (Appendix M.2); 2) climatic niche models for general vegetation types (Appendix M.3); and 3) mechanistic vegetation models for plant functional types (Appendix M.3).[ii]

For upland areas, both the climatic niche and mechanistic models of vegetation change project a loss of alpine and sub-alpine forest vegetation types (Appendix M.3). The mechanistic model projects an expansion of mid-elevation needle-leaf forest ("cool" forest) or possibly temperate mixed needle and broad-leaf forest ("cool open forest/woodland") (Appendix M.3). The climatic niche model also projects expansion of montane, low to mid-elevation forest types, which is broadly similar to the mechanistic model projections. However, the climatic niche model also projects expansion of Great-Basin Shrub Grassland and, in some scenarios, Great-Basin Desert and Montane Scrub (drier grassland-shrub habitat types) into some of the lower elevation regions (Appendix M.3).

There is more disagreement among projections for the Okanagan Valley. The climatic niche models generally agree that the Okanagan Valley is projected to remain climatically suitable for sagebrush (either the species or the Great-Basin Shrub Grassland vegetation type) and that climate conditions along lower slopes adjacent to the Valley increase in climatic suitability for sagebrush. However, the mechanistic model, which models current vegetation in the Okanagan Valley as grassland as opposed to shrub steppe, projects forest encroachment into the Valley by the end of the century. The mechanistic models are process based and incorporate climate, but also changes in other ecological drivers such as fire regime, competitive interactions, and carbon dioxide fertilization. In contrast, the climatic niche models rely solely on correlative models and climate data alone. While it is difficult to identify which of

[ii] Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

these factors is driving forest encroachment, one possibility is that carbon dioxide fertilization increases the water use efficiency of trees, allowing them to survive in areas that would otherwise be too arid. Rogers et al. (2011) used a different type of mechanistic vegetation model to project vegetation changes in western Washington and Oregon.[10] Although their study extent only includes a small portion of the Okanagan-Kettle region, this model also projected an expansion of low to mid-elevation forest at the expense of subalpine forest and forest encroachment into areas of the Okanagan Valley that were previously grassland.

The discrepancy between these model projections highlights our uncertainty about how vegetation will react to changing climate conditions. While there is some good evidence that climate conditions will remain suitable for a grassland-shrub system in the Okanagan Valley, other factors, such as carbon dioxide fertilization, could change the way that different species respond to climate change.

Changes in hydrology

Changes in hydrology may affect connectivity for a variety of habitat types in the Okanagan-Kettle region. Climate models project that spring precipitation for the region will increase (Appendix M.4: Spring Precipitation), but that summer precipitation (Appendix M.4: Summer Precipitation) and spring and summer runoff will decrease (Appendix M.4: Spring Runoff; Summer Runoff). These changes may reduce water availability to fill ponds and maintain wetland habitats. On the other hand, spring evapotranspiration is projected to increase (Appendix M.4: Evapotranspiration, March-May), while summer evapotranspiration is projected to decrease or stay the same at low to mid-elevations (Appendix M.4: Evapotranspiration, July-September). A decrease in evapotranspiration means that water evaporates more slowly, theoretically leaving more water in ponds. However, soils in the Okanagan-Kettle region are highly permeable to precipitation. Frost can create a moisture seal, decreasing permeability and increasing runoff into depressions, feeding wetlands and ponds. Climate change is projected to reduce the number of frost days by roughly 40-80% by the 2080s in the Okanagan Valley (Appendix M.4: Number of Frost Days), depending on location and climate scenario. Projected declines are less severe in the uplands, however, depending on the climate scenario and location, decreases may still range from 10-80%. It is not necessary to have a frost seal every year to fill ponds adequately, but if frost seals fail to occur in several consecutive years, there could be an impact on wetlands. Thus, potential changes in hydrology and reductions of frost days may negatively affect aquatic habitat connectivity in the Okanagan-Kettle region.

Changes in hydrology may also affect riparian habitats. Runoff from extreme precipitation events (Appendix M.4: Number of Heavy Precipitation Days; Average Precipitation Intensity) could scour riparian forests and remove trees and shrubs. Both of these impacts would reduce the quality of low elevation riparian corridors used by montane forest species moving among higher elevation habitats.

Changes in disturbance regimes

Climate change may affect habitat connectivity in the Okanagan-Kettle region by increasing the frequency and severity of summer drought (Appendix M.4: Water Deficit, July-September; Soil Moisture, July-September) and increasing the risk of wildfires (Appendix M.4: Days with High Fire Risk).

Forested riparian areas comprise important movement corridors for montane forest species moving though grassland and scrub habitats in warm, low elevation valleys in the Okanagan-Kettle region, including the Okanagan Valley. Increased fire frequency (Appendix M.4: Days with High Fire Risk) could affect habitat connectivity for montane forest species by reducing forest cover in low-elevation corridors. Increased wildfire is also likely to have a major impact on regional forest and shrub-steppe habitats. Fire is a critical driver of vegetation type in this region. To some extent, an increase in fire frequency or intensity may favor a shift from forest to grassland/scrub. One available model predicts an increase in days with high fire risk for Washington (Appendix M.4: Days with High Fire Risk), and another predicts an increase in area burned and an increase in fire intensity (as measured by biomass consumed) for parts of Washington.[10] For the latter model, fire suppression was not able to mitigate the increase in fire impacts due to climate change.

Changes in invasive species

Cheatgrass is an invasive species with devastating affects on shrub-steppe communities. Climate change could influence the distribution and invasiveness of cheatgrass due to its sensitivity to changes in temperature, precipitation, and fire regime.[11] Cheatgrass climatic niche models (CNMs) for the greater Columbia Plateau project either no change or a shrinking climatic niche space for cheatgrass,[12] which would have a positive affect on shrub-steppe habitat connectivity. However, CNMs do not account for the influence of fire on habitat suitability. Projected increases in fire risk (Appendix M.4: Days with High Fire Risk) may promote cheatgrass invasion in shrub-steppe communities, negatively affecting habitat connectivity.

Adaptation Responses

After identifying potential climate impacts on landscape and wildlife habitat connectivity, project participants identified which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts on habitat connectivity in the Okanagan-Kettle region. Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on wildlife habitat connectivity on existing corridors (Appendix M.1), those that address novel habitat connectivity needs for promoting climate-induced shifts in species distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on wildlife habitat connectivity

Actions to address climate impacts on habitat connectivity across systems (e.g., montane, shrub-steppe, and aquatic) include:

- Restoring and maintaining riparian areas. This would enhance aquatic habitat connectivity by shading ponds and streams, helping to reduce water temperatures and evaporation rates. This would also help enhance habitat connectivity for montane forest species, which often use riparian areas to cross dry, low elevation valleys. Because they span climatic gradients, riparian areas may also help promote species range shifts in response to warming. Be prepared to increase restoration efforts in response to flood damage from extreme precipitation events.
- Identifying and protecting wetlands and other water sources in valleys. These may help to promote movement of montane forest species through dry, low-elevation valleys, while also promoting core habitat area and corridor quality for aquatic species, including amphibians.
- Restoring beavers to suitable unoccupied habitat to improve riparian and aquatic habitat quality and retention. This would help promote movement of montane forest species across open valley bottoms, and habitat quality and movement of aquatic species within valley bottoms.
- Maintaining as many high quality linkages as possible, as increased disturbance may at least temporarily degrade individual core habitat areas and corridors.

Additional actions to address climate impacts on low-elevation corridors for montane forest species (e.g., black bear) include:

- Monitoring low-elevation corridors for vegetation changes that may affect habitat connectivity for montane forest species. If shrub steppe vegetation appears to be expanding, cross-valley corridors may become longer, making them less attractive to dispersing montane forest species. Conversely, if forest expands into the valley, corridor suitability may increase for montane forest species. Monitoring would allow timely modification of connectivity conservation efforts to account for these or other possible changes.

Additional actions to address climate impacts on habitat connectivity for shrub-steppe species (e.g., western rattlesnake) include:

- Using frequent, low-intensity prescribed burns to reduce the risk of catastrophic wildfires that could negatively impact shrub-steppe core habitat areas and corridors. More frequent, smaller fires may promote a patchy mosaic that can help prevent large, catastrophic fires. In developed areas, implementing a new prescribed burn program would require careful evaluation of associated risks and benefits.
- In areas heavily invaded by cheatgrass, considering prescribed burning in combination with herbicide and native plant reseeding efforts.[13]
- Incorporate invasive species management into all activities related to habitat connectivity conservation.
- Referencing the practices of tribes and First Nations to identify traditional strategies for managing fire risk and other potential climate impacts.
- Incorporating projections and observations of climatic changes to inform the timing of fire prevention techniques as conditions change, in order to maximize safety and effectiveness.

Additional actions to address climate impacts on habitat connectivity for aquatic and amphibian species (e.g., tiger salamander) include:

- Maintaining wetlands. If frost seal does not occur often enough to maintain wetlands, consider using artificial irrigation to maintain key wetlands.
- Excluding cattle from ponds and surrounding vegetation (e.g., by installing cattle fencing), and using techniques (e.g., fabric and gravel installation) to prevent cattle from leaving pockmarks, which reduce pond quality.
- Widening ponds to increase access for salamanders and/or deepening ponds to increase pond persistence into summer (while maintaining slope to allow salamander access).
- Adding water and removing predatory fish from targeted ponds. Because this strategy would be highly resource intensive it should be considered an emergency measure to be implemented only if necessary.
- Establishing retention ponds in urban areas, which would mitigate increased flooding in winter and spring while also increasing available tiger salamander habitat. These areas could be treated as managed wetlands.
- Diverting rainwater into existing tiger salamander ponds. This option should be carefully considered in light of possible chemical run-off and turbidity issues.

Enhancing connectivity to facilitate range shifts

Actions that may help wildlife in the Okanagan-Kettle region adjust their geographic distributions to track shifts in areas of climatic suitability include:

- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors[6]), to ensure that species have the ability to disperse into cooler, higher elevation habitats as the climate warms. It will be especially important to provide connectivity among warm valley floors (particularly within the Okanagan Valley) and cooler high elevation locations.
- Monitoring and coordinating with transportation planning processes to minimize road impacts on climate-gradient corridors (e.g., by incorporating crossing structures or avoiding building new roads that cross climate-gradient corridors).
- Focusing habitat retention efforts on riparian habitats, which span climatic gradients and are frequently used by wildlife as movement corridors.

Spatial priorities for implementation

Connectivity focus areas identified for the Okanagan-Kettle region (Appendix M.1)[2] offer critical areas for implementing the adaptation actions identified above, in order to maintain regional habitat connectivity as the climate changes. Among these areas, those identified as having habitat connectivity value for shrub-steppe and montane species, as well as landscape integrity, include:

- **East–west trending valleys extending from the Okanagan Valley in BC** (e.g., northwest of Vernon, the Lumby Valley, east of Kelowna (following Hwy 33), west of Peachland (following Hwy 97C), the Similkameen Valley at Keremeos, and east of Osoyoos). These valleys support movement of shrub-steppe species extending out from the Okanagan Valley, as well as north–south movements of montane species.
- **The area north of Vernon, BC**, which may facilitate movement across the valley to higher elevation habitats and provide connectivity with shrub-steppe communities in the northwest.
- **The area between Okanagan Falls and Osoyoos, BC**, including the Okanagan Valley along Hwy 97 as well as along Hwy 3 where it passes west through Marron Valley, Olalla, Keremeos, and Cawston. Many Okanagan-Kettle region connectivity focus areas occur here, reflecting this area's importance for regional connectivity, as well as the pressure of ongoing habitat conversion to agriculture and urbanization.
- **East of Osoyoos, BC**. Development here has the potential to sever a narrow north–south linkage for shrub-steppe species moving along the east side of the Okanagan Valley, as well as north–south movement of montane species along the eastern rim of the valley at higher elevations.
- **South of Oroville, WA (near Mt Hull), and near Riverside, WA on the US side of the Okanagan Valley**. These areas provide north–south movement for shrub-steppe species along the Okanagan and offer opportunities for montane species to cross the Okanagan along an east–west axis. The area near Riverside has been identified by previous analyses as key for linking forested habitat of the North Cascades eastward through the Okanagan Valley and Highlands to the Kettle Range.
- **Along the Similkameen Valley between Keremeos and Princeton, BC,** where several bottlenecks exist for shrub-steppe species moving between the Okanagan Valley and shrub-steppe habitat north of Princeton. These same areas provide opportunities for north–south movements of montane species across the Similkameen Valley.
- **The area north of Princeton, BC,** which may be important for maintaining east–west

connectivity of higher elevation habitats as well as providing potential future access to shrub-steppe areas in the Nicola Valley and north to Merritt and beyond.

References

1. Krosby, M., Michalak, J., Robbins, T.O., Morgan, H., Norheim, R., Mauger, G., and T. Murdock. 2016. The Washington-British Columbia Transboundary Climate-Connectivity Project: Identifying climate impacts and adaptation actions for wildlife habitat connectivity in the transboundary region of Washington and British Columbia. Climate Impacts Group, University of Washington.
2. Transboundary Connectivity Group. 2016. Providing a Regional Connectivity Perspective to Local Connectivity Conservation Decisions in the British Columbia–Washington Transboundary Region: Okanagan-Kettle Subregion Connectivity Assessment. www.waconnected.org.
3. Krosby, M., Tewksbury, J. J., Haddad, N., and J. Hoekstra. 2010. Ecological connectivity for a changing climate. *Conservation Biology* 24:1686-1689.
4. Cross, M. S., Hilty, J. A., Tabor, G. M., Lawler, J. J., Graumlich, L. J., and J. Berger. 2012. From connect-the-dots to dynamic networks: Maintaining and restoring connectivity as a strategy to address climate change impacts on wildlife. *In*: J. Brodie, E. Post, D. Doak, eds. *Conserving wildlife populations in a changing climate*. Chicago University Press.
5. Heller, N. E., and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation* 142**:**14–32.
6. Washington Wildlife Habitat Connectivity Working Group. 2011. Washington Connected Landscapes Project: Climate gradient corridors report. Washington Departments of Fish and Wildlife, and Transportation. Olympia, WA. www.waconnected.org.
7. Integrated Scenarios of the Future Northwest Environment. http://climate.nkn.uidaho.edu/IntegratedScenarios
8. Pacific Climate Impacts Consortium (PCIC), Regional Analysis Tool. 2014. https://www.pacificclimate.org/analysis-tools/regional-analysis-tool
9. Pacific Northwest Climate Change Vulnerability Assessment (PNWCCVA). http://www.climatevulnerability.org/
10. Rogers, B.M., Neilson, R.P., Drapek, R., Lenihan, J.M., Wells, J.R., Bachelet, D., and B. E. Law. 2011. Impacts of climate change on fire regimes and carbon stocks of the U.S. Pacific Northwest. *Journal of Geophysical Research* 116: G03037, doi:10.1029/2011JG001695.
11. Michalak, J.L., Whitey, J.C., Lawler, J.J., Hall, S., and T. Nogeire. 2014. Climate vulnerability and adaptation in the Columbia Plateau, WA. Report prepared for the Great Northern Landscape Conservation Cooperative. School of Environmental and Forest Sciences, University of Washington, Seattle, WA.
12. Bradley, B.A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. *Global Change Biology* 15:196-208.
13. USFS. Field guide for managing cheatgrass in the Southwest. 2014. *TP-R3-16-04*.

Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[iii]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[iv] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

[iii] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).
[iv] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices M.1-4

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For the Okanagan-Kettle region, these materials include:

Appendix M.1. Habitat connectivity models
Appendix M.2. Climatic niche models
Appendix M.3. Projected changes in vegetation communities
Appendix M.4. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Transboundary Connectivity Group[2] and Washington Connected Landscapes Project,[6] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[7] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[8] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[9]

All maps are provided at the geographic extent of the Okanagan-Kettle region (Fig. M.2), which was the assessment area for project partners the Transboundary Connectivity Group (i.e., the Washington Habitat Connectivity Working Group and its partners in British Columbia). Assessment areas and partners for the full Washington-British Columbia Transboundary Climate-Connectivity Project included (Fig. M.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.

ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).

iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at:
https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

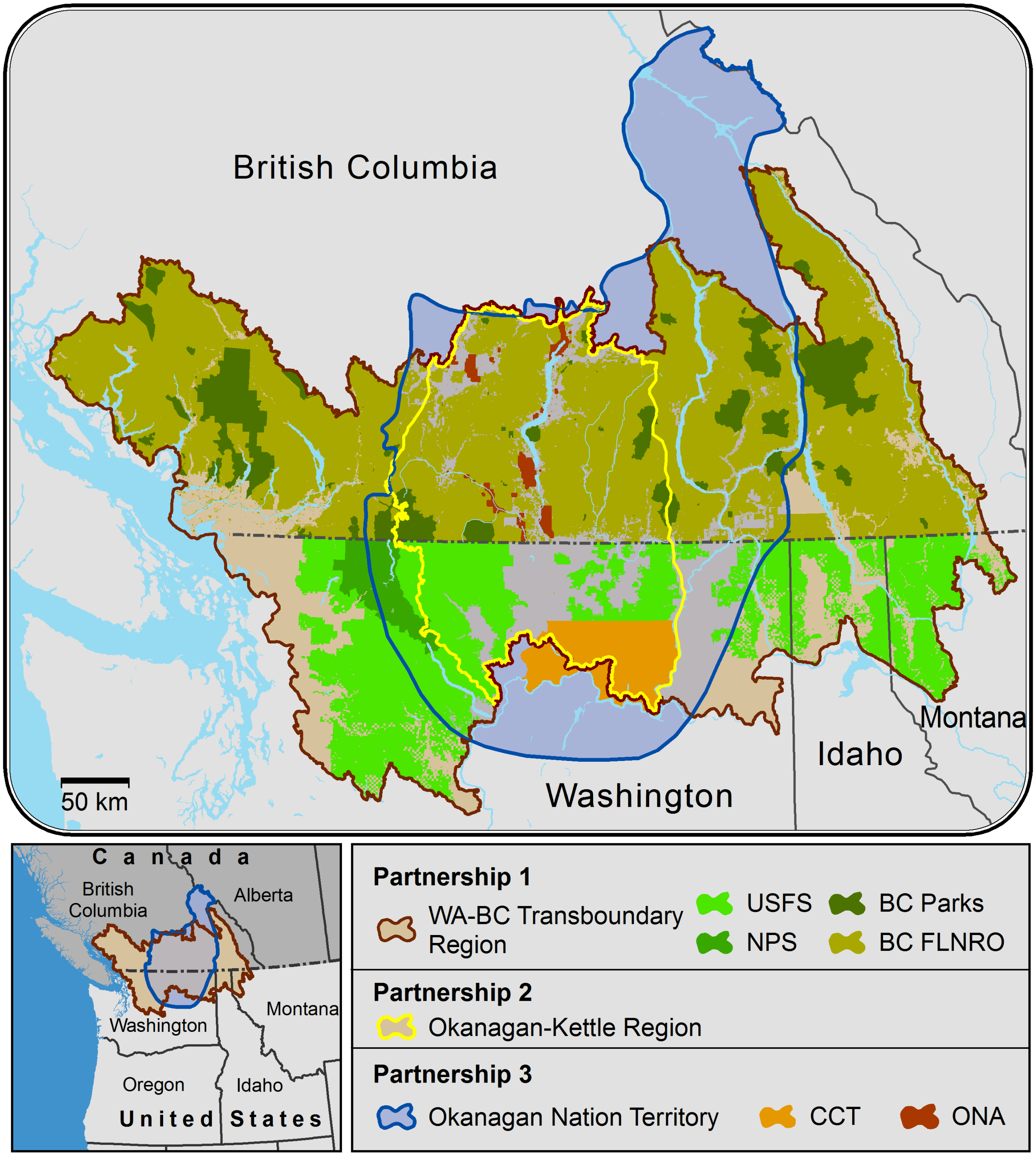


Figure M.2. Project partners and assessment areas.

Appendix M.1. Habitat Connectivity Models

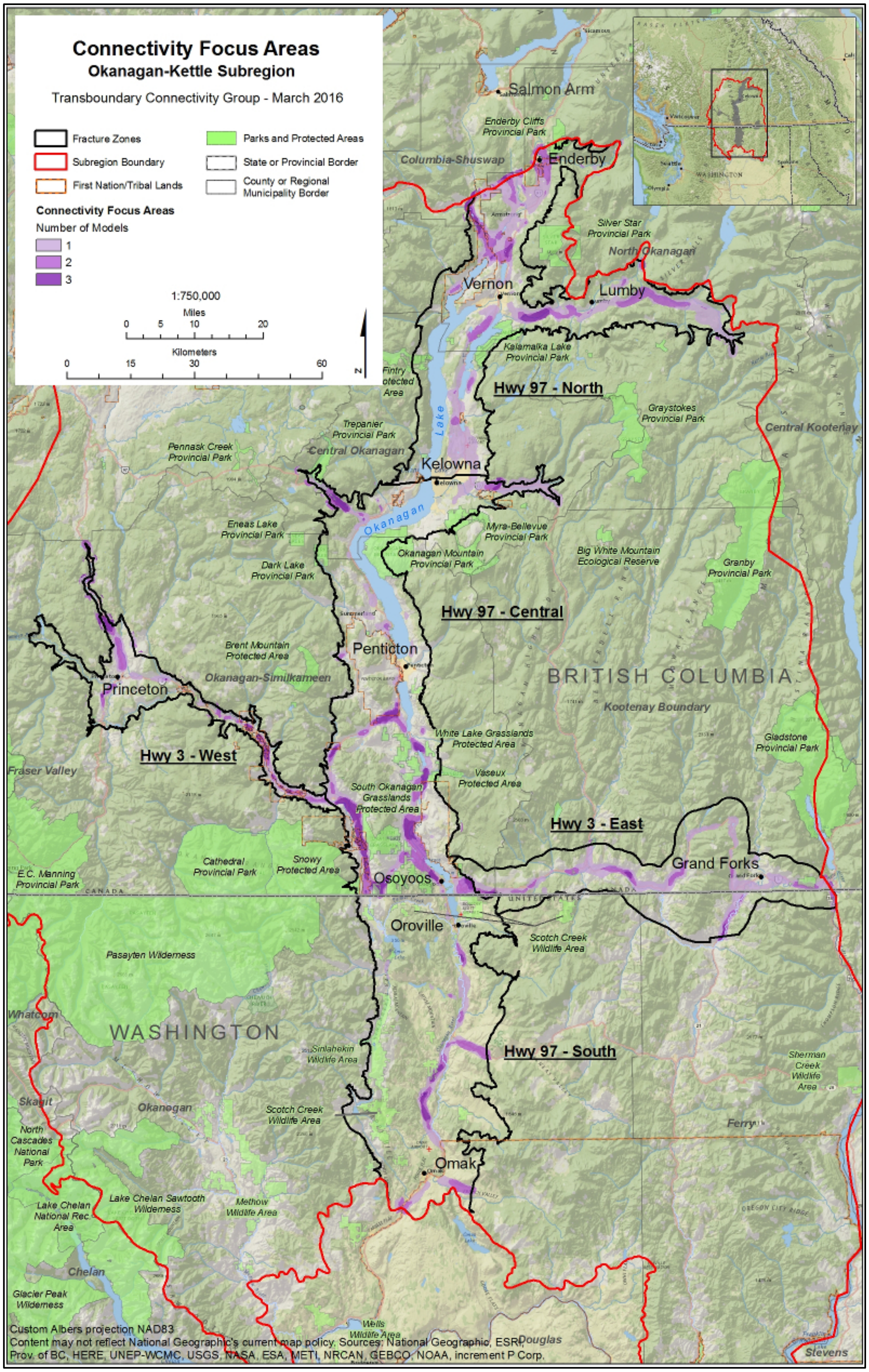
Habitat connectivity models for the Okanagan-Kettle region are available from the Transboundary Connectivity Group and the Washington Connected Landscapes Project.[v] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models that may be useful for the Okanagan-Kettle region include:

a) **Okanagan-Kettle Connectivity Assessment: Connectivity Focus Areas.**[2] This map shows connectivity focus areas (CFAs) identified for the Okanagan-Kettle region. CFAs (in purple) used connectivity value and development risk models to identify those places within the Okanagan-Kettle region where wildlife would likely move when migrating or making dispersal movements and that are also the most threatened by potential development. This map shows a composite of CFAs for shrub-steppe species, montane species, and landscape integrity models; CFAs move from pink to purple with increasing number of overlapping models.

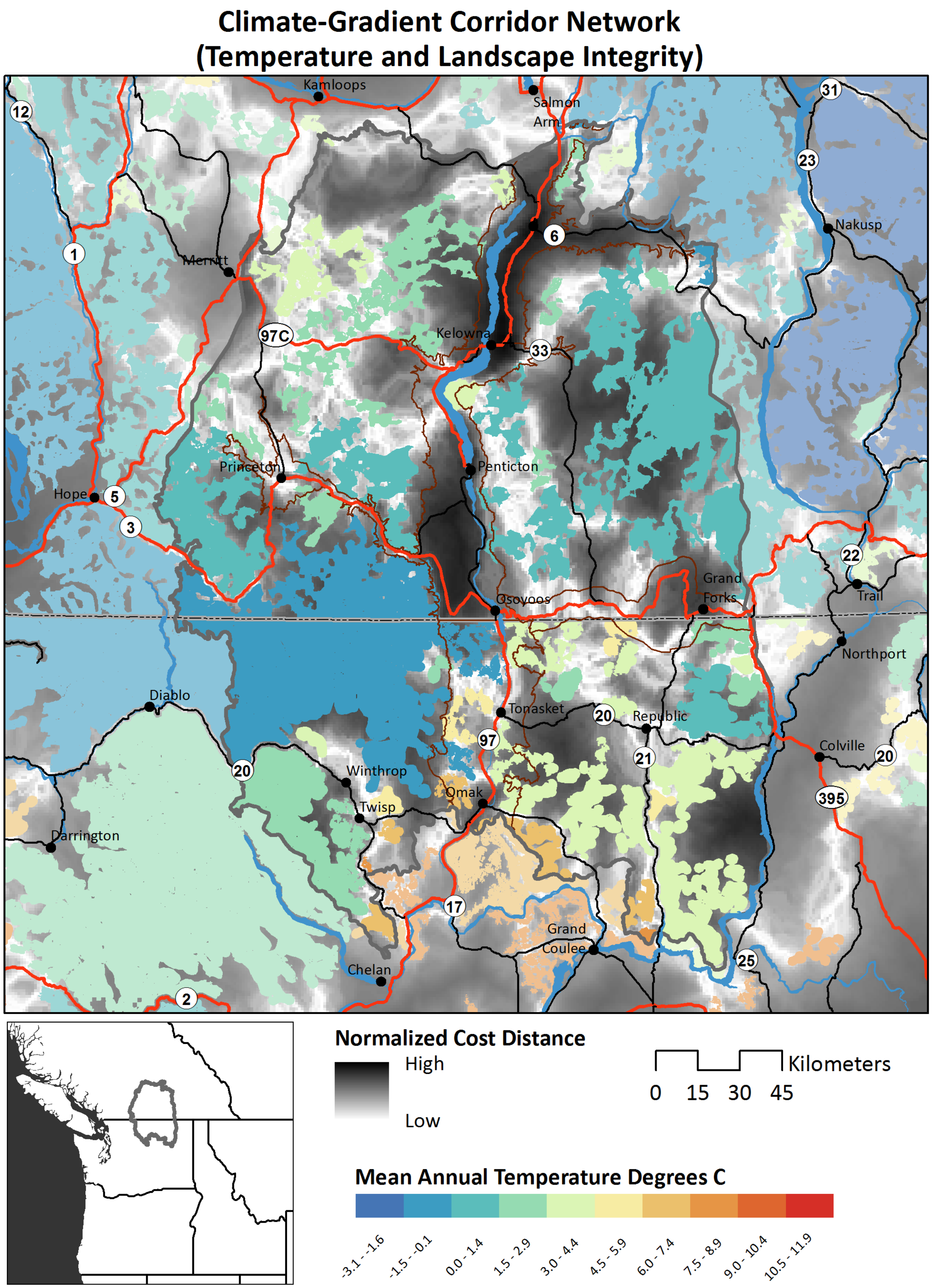
b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).**[6] This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[v] For detailed methodology and data layers see http://www.waconnected.org.

Appendix M.1a. Okanagan-Kettle Connectivity Assessment: Connectivity Focus Areas



Appendix M.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)



Appendix M.2. Climatic Niche Models

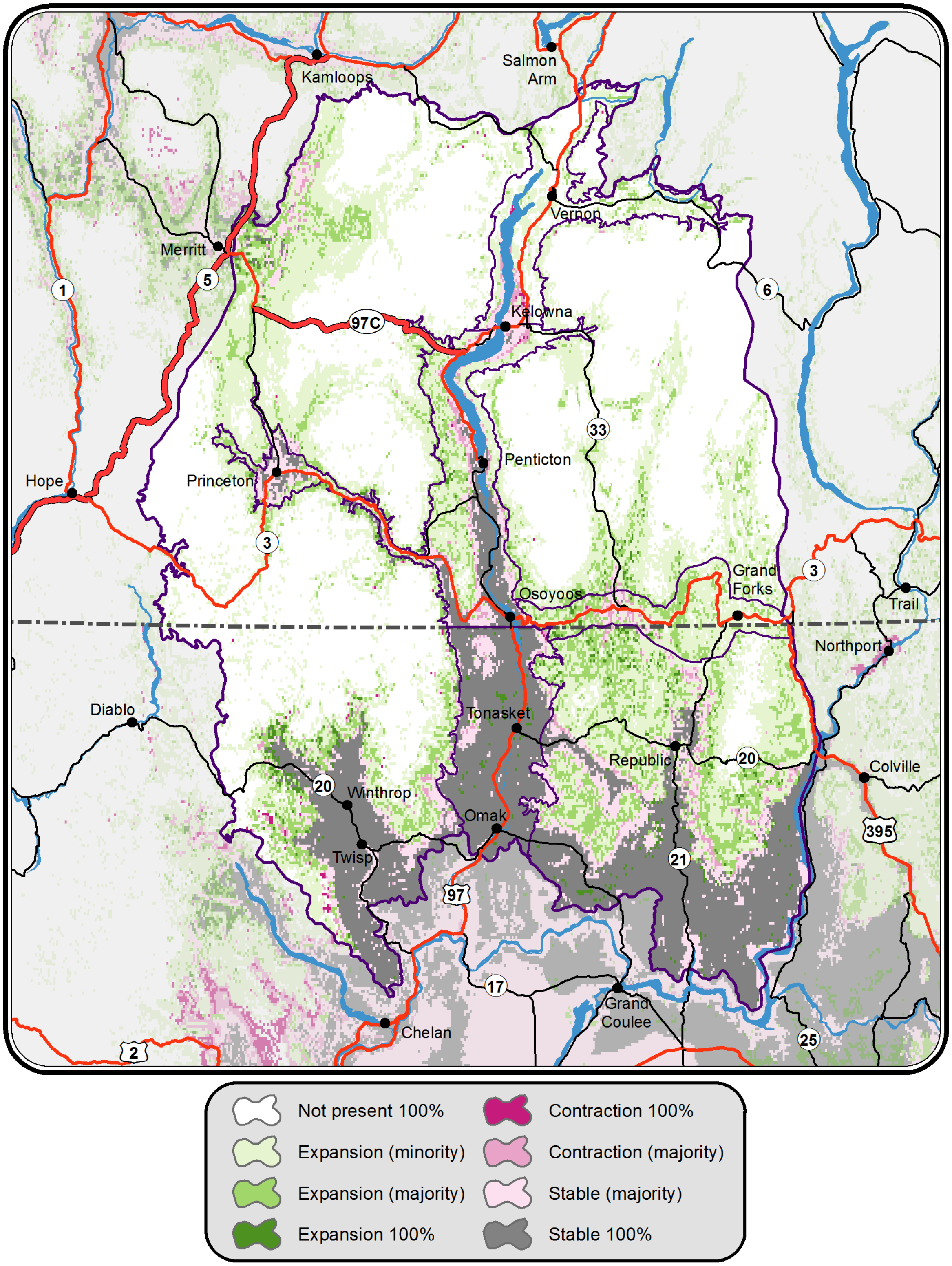
Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[vi] Both models use the A2 (high) emissions scenario.[vii] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[viii]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

[vi] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.
[vii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.
[viii] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

Appendix M.2. Sagebrush Climatic Niche Model

Sagebrush spp.-*Artemisia tridentata*



Appendix M.3. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[ix] Both models also use the A2 (high) emissions scenario.[x]

a) **Biome Climatic Niche Vegetation Model.**[xi] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xii] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

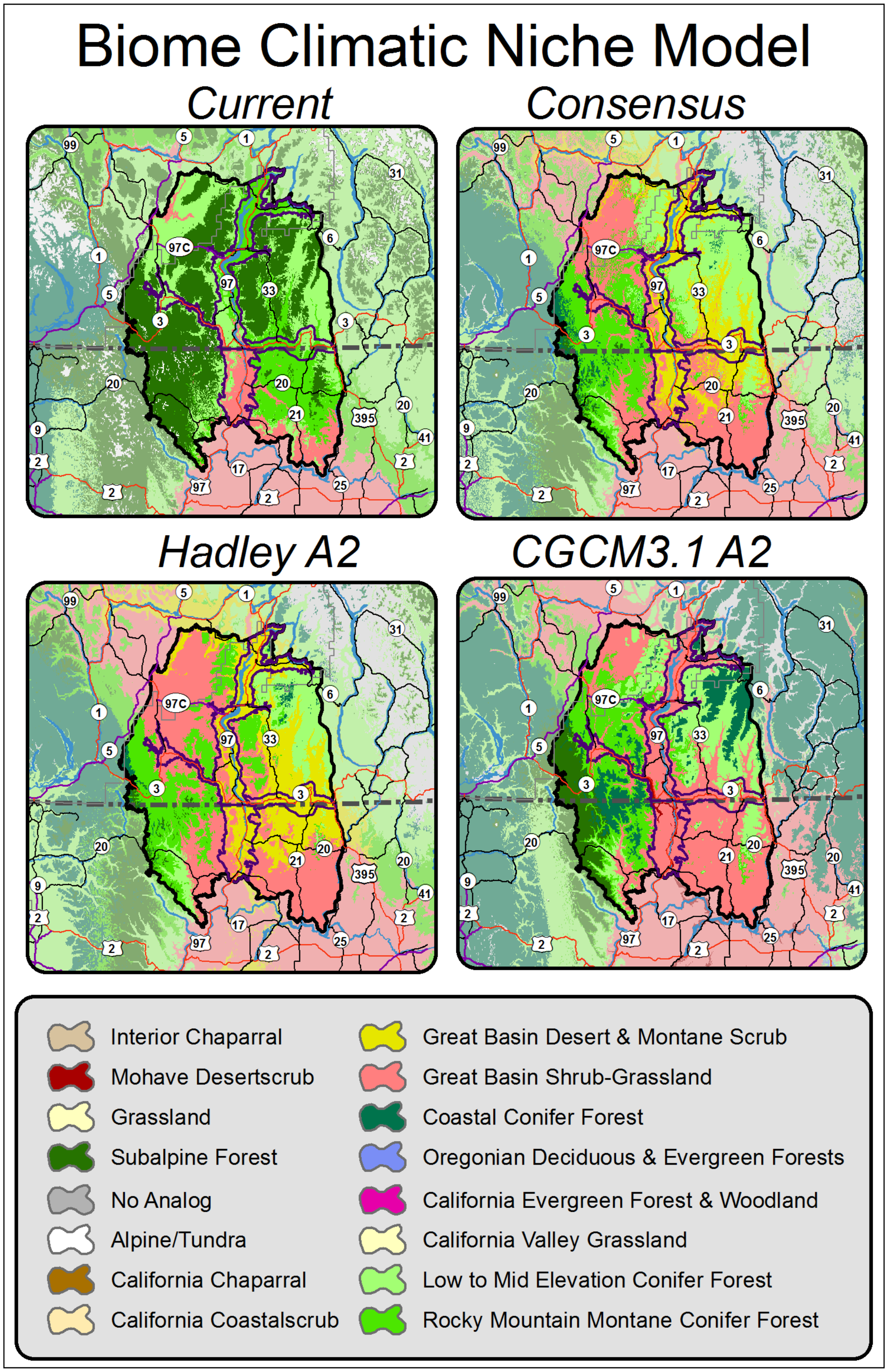
[ix] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[x] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

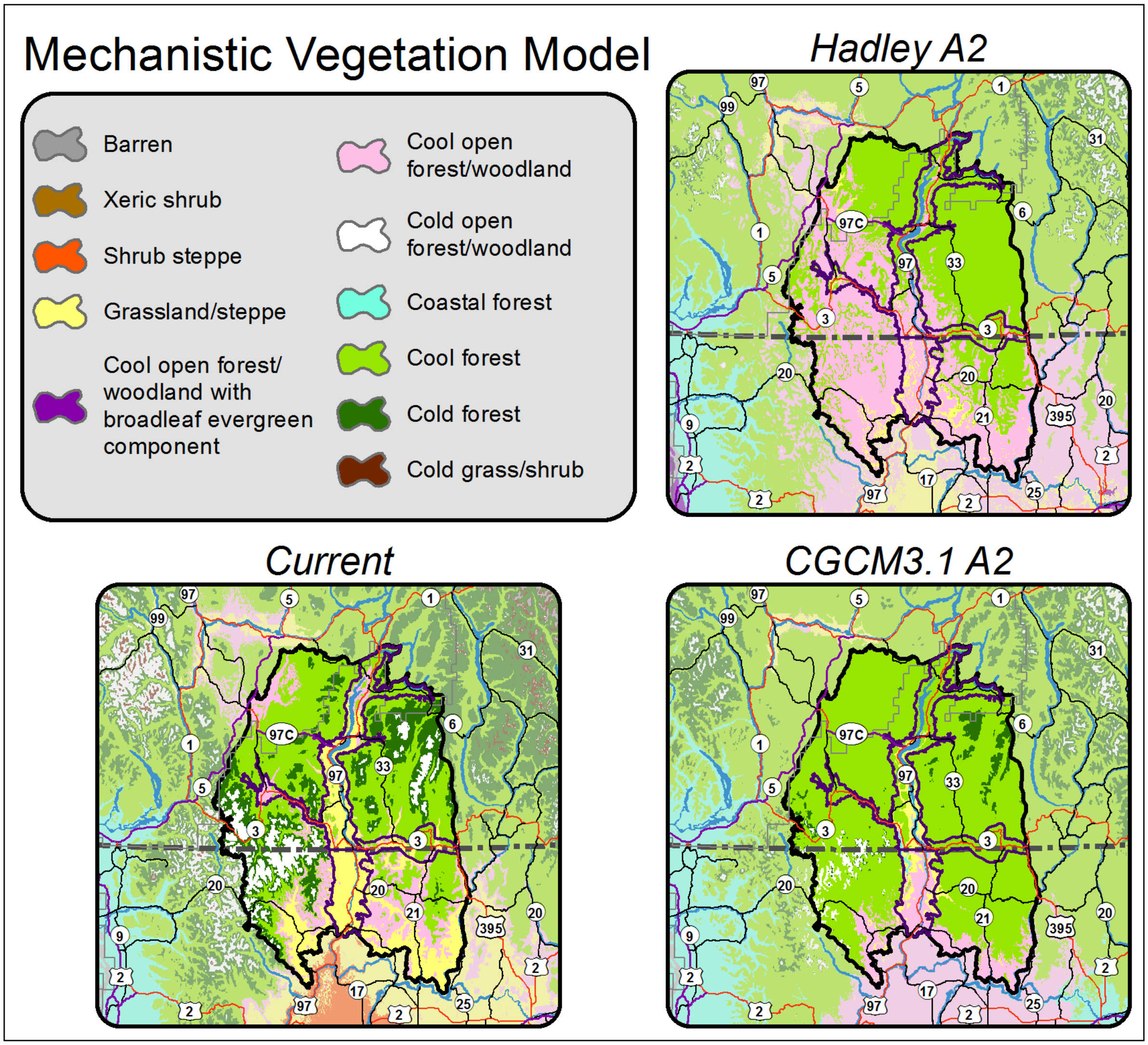
[xi] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xii] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

Appendix M.3a. Biome Climatic Niche Model



Appendix M.3b. Mechanistic Vegetation Model



Appendix M.4. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on habitat connectivity in the Okanagan Kettle region.[xiii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[8] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Total Spring Precipitation, March-May.** This map shows the projected change, in percent, in total spring (March-May) precipitation. Projected changes in total spring precipitation are depicted by the yellow to green shading.

b) **Total Summer Precipitation, June-August.** This map shows the projected change, in percent, in total summer (June-August) precipitation. Projected changes in total summer precipitation are depicted by the teal to brown shading.

c) **Total Spring Runoff.** This map shows projected change, in percent, in spring (March-May) runoff. This includes any overland water flows in addition to subsurface runoff in shallow groundwater. Projected changes in spring runoff are depicted by the yellow to green shading.

d) **Total Summer Runoff.** This map shows projected change, in percent, in summer (July-September) runoff. This includes any overland water flows in addition to subsurface runoff in shallow groundwater. Projected changes in summer runoff are depicted by the teal to brown shading.

e) **Evapotranspiration, March-May.** This map shows the percent change in evapotranspiration between March and May. Projected changes in spring evapotranspiration are depicted by the yellow to red shading.

f) **Evapotranspiration, July-September.** This map shows the percent change in evapotranspiration between July and September. Projected changes in summer evapotranspiration are depicted by the teal to brown shading.

g) **Number of Heavy Precipitation Days.** This map shows projected change, in percent, in the number of heavy precipitation days, defined as the annual count of days with at least 10 mm of precipitation. Projected changes in heavy precipitation days are depicted by the yellow to green shading.

[xiii] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

h) **Average Precipitation Intensity.** This map shows projected change, in percent, in the average precipitation intensity. Projected changes in precipitation intensity are depicted by the yellow to green shading.

i) **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.

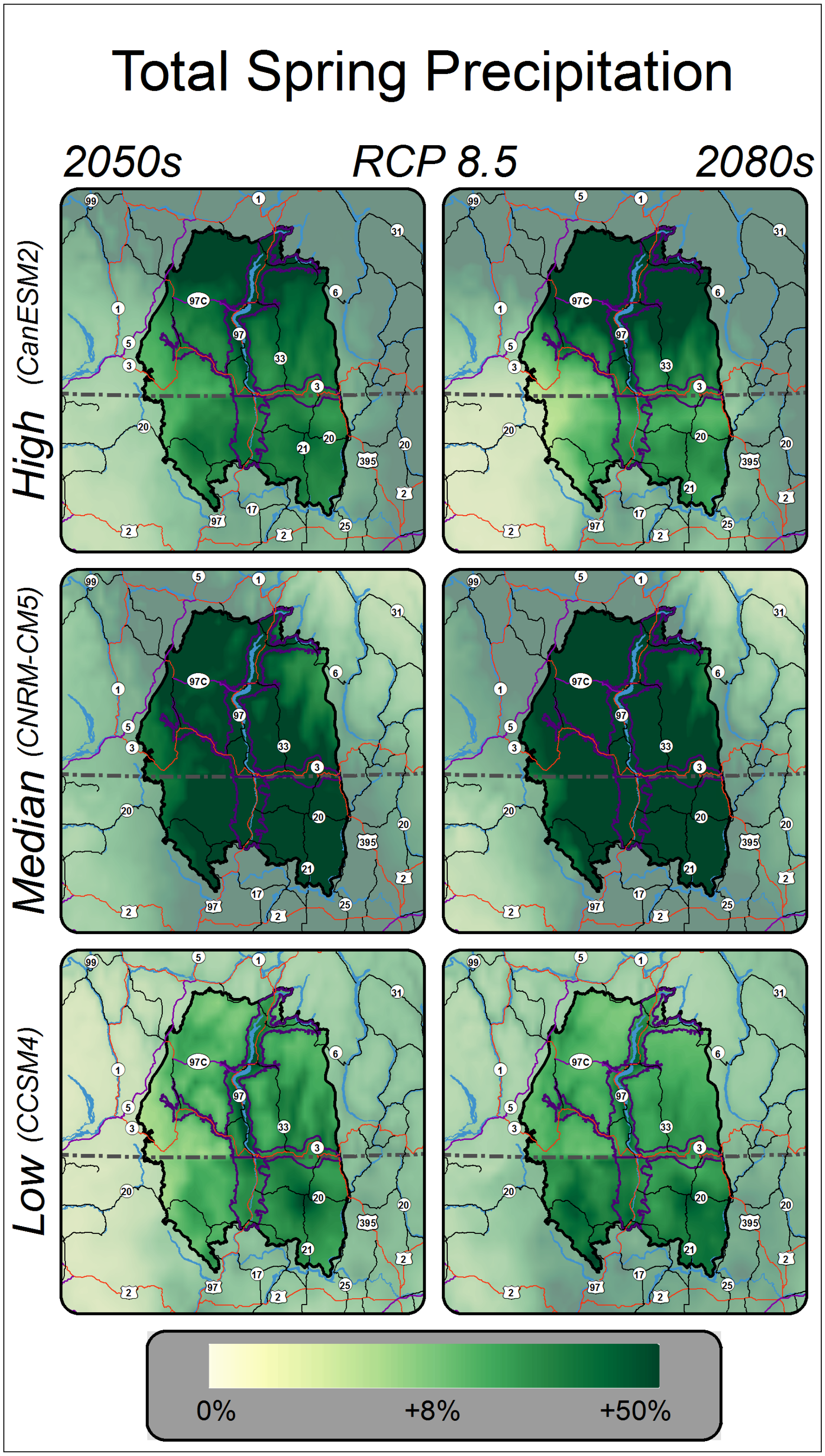
j) **Water Deficit, July-September.** This map shows the projected change, in percent, in water deficit. Water deficit is defined as the difference between potential evapotranspiration (PET) and actual evapotranspiration (AET), PET - AET. A positive value for PET – AET means that atmospheric demand for water is greater than the actual supply available.

k) **Number of Frost Days.** This map shows the projected change, in percent, in the number of frost days, defined as the annual count of days when the daily minimum temperature is less than 0 degrees Celsius. Projected changes in the number of frost days are depicted by the yellow to red shading.

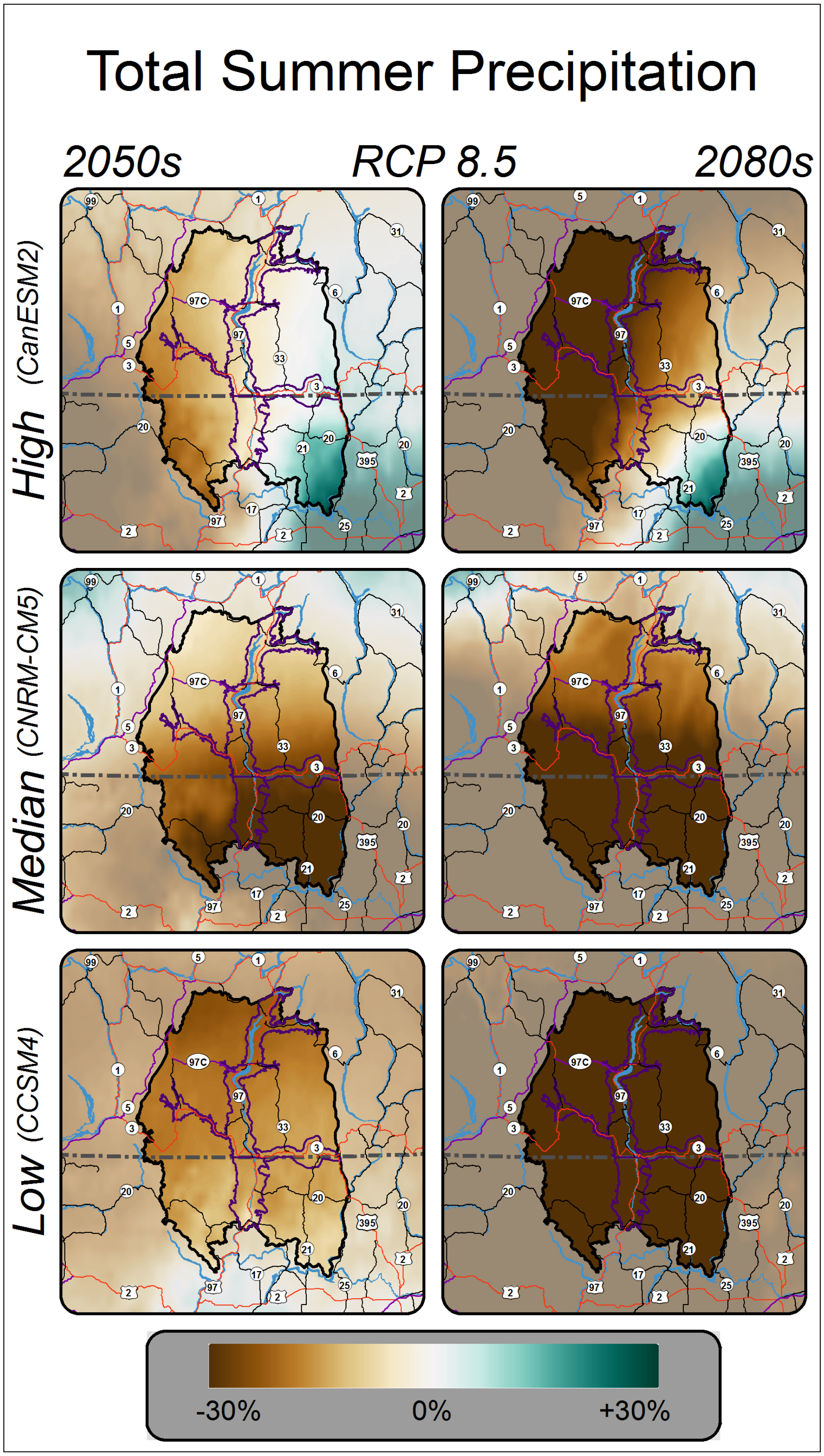
l) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile). This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.[xiv]

[xiv] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.

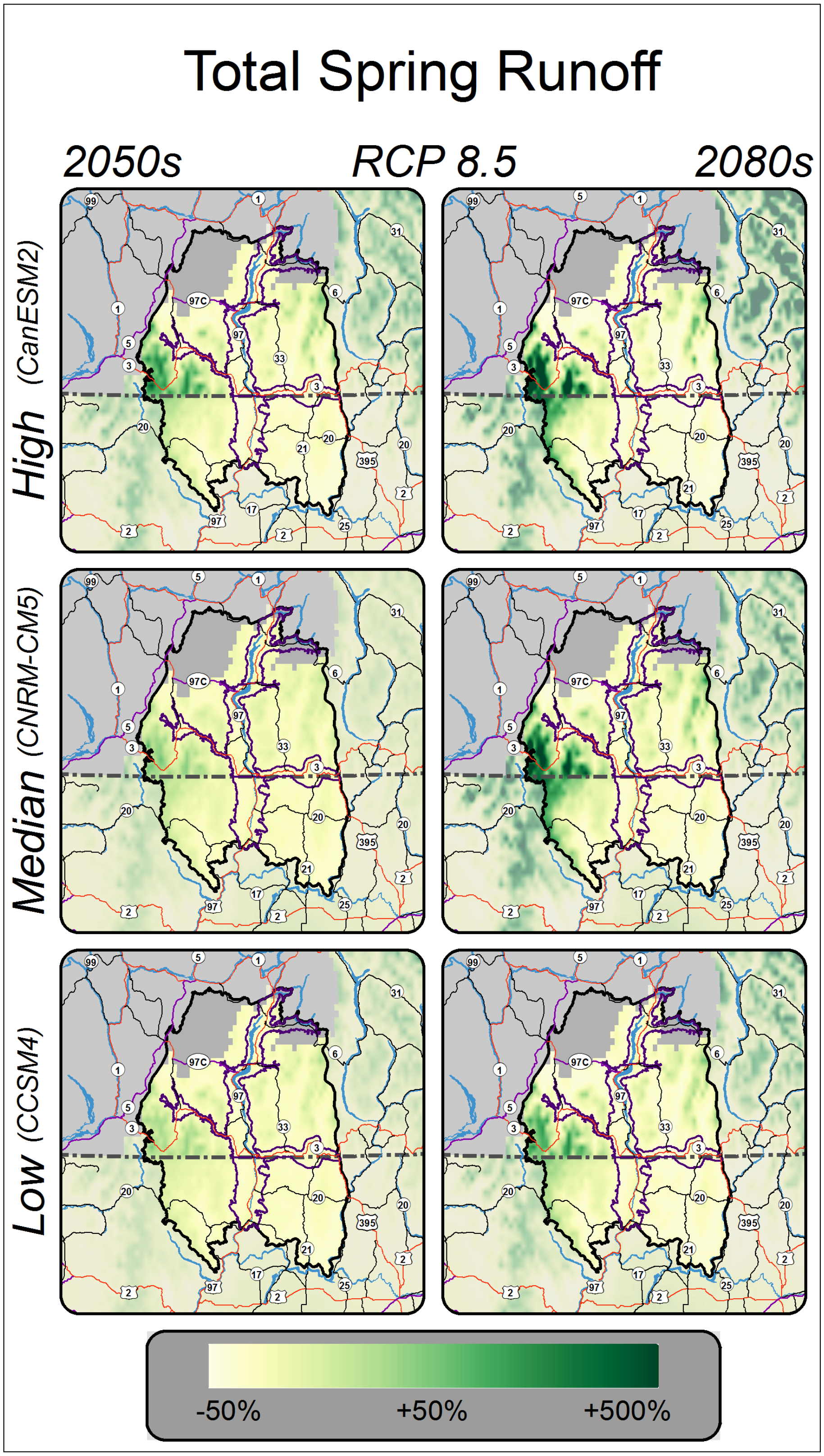
Appendix M.4a. Total Spring Precipitation



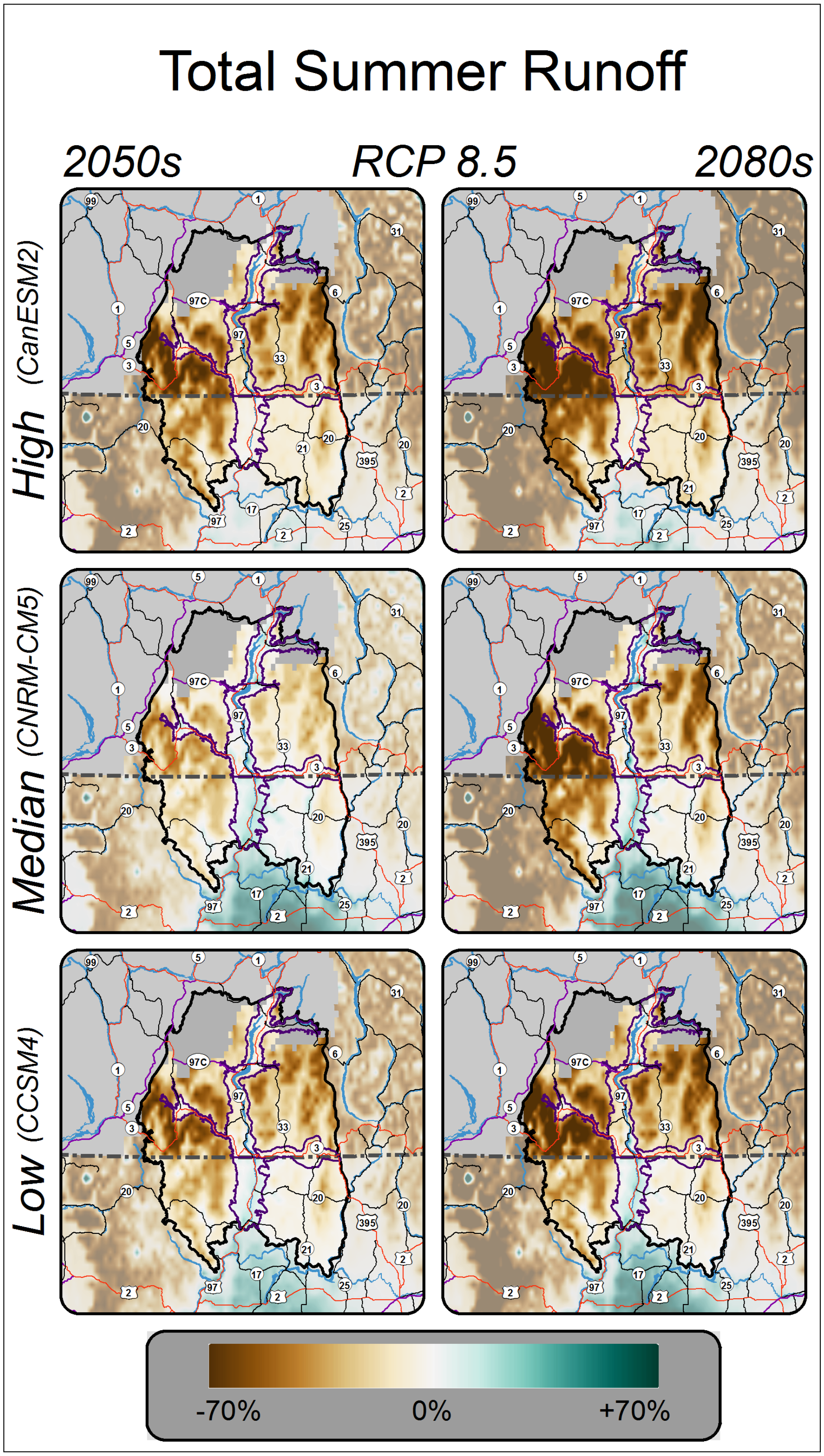
Appendix M.4b. Total Summer Precipitation



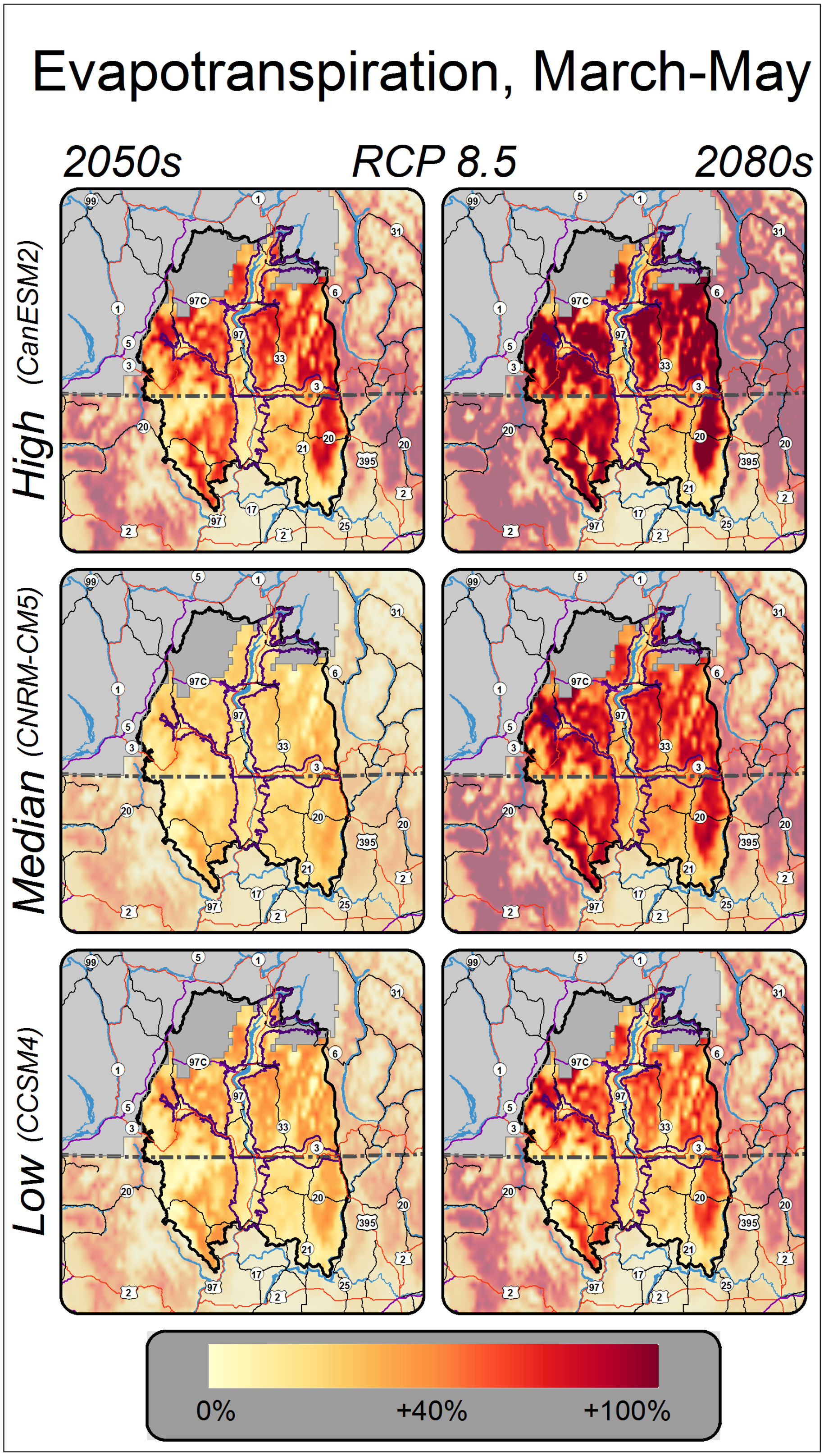
Appendix M.4c. Total Spring Runoff



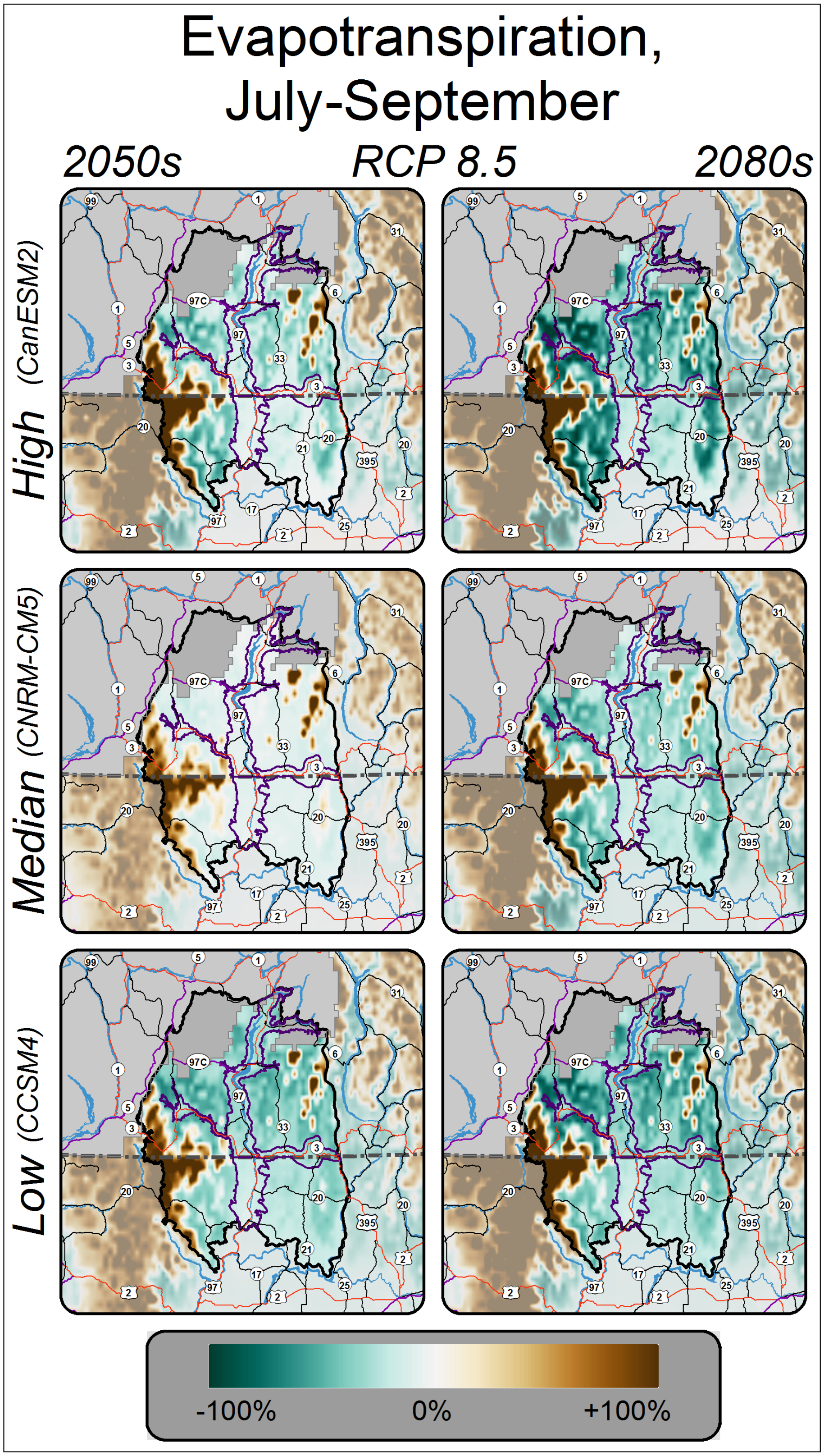
Appendix M.4d. Total Summer Runoff



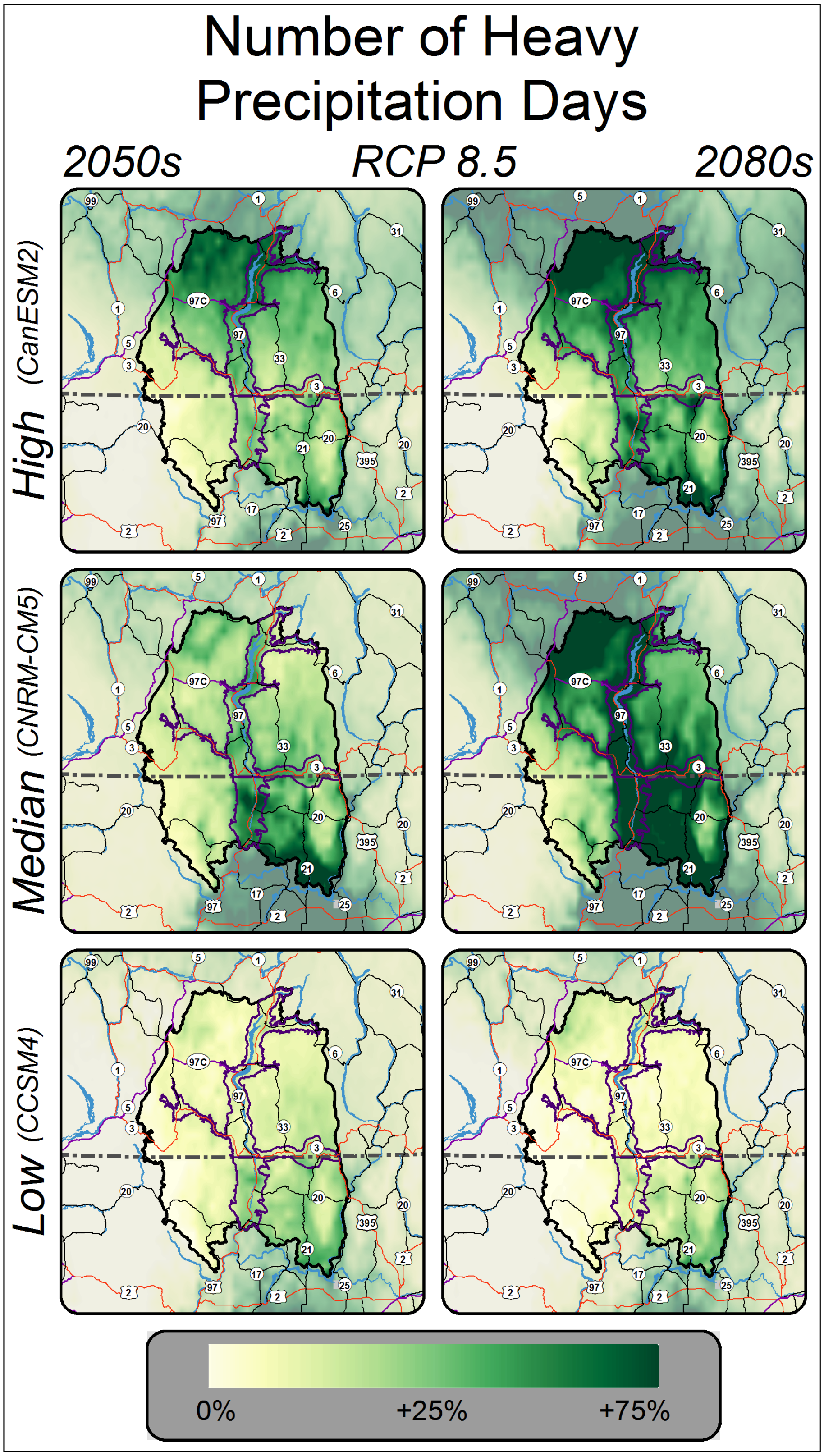
Appendix M.4e. Evapotranspiration, March-May



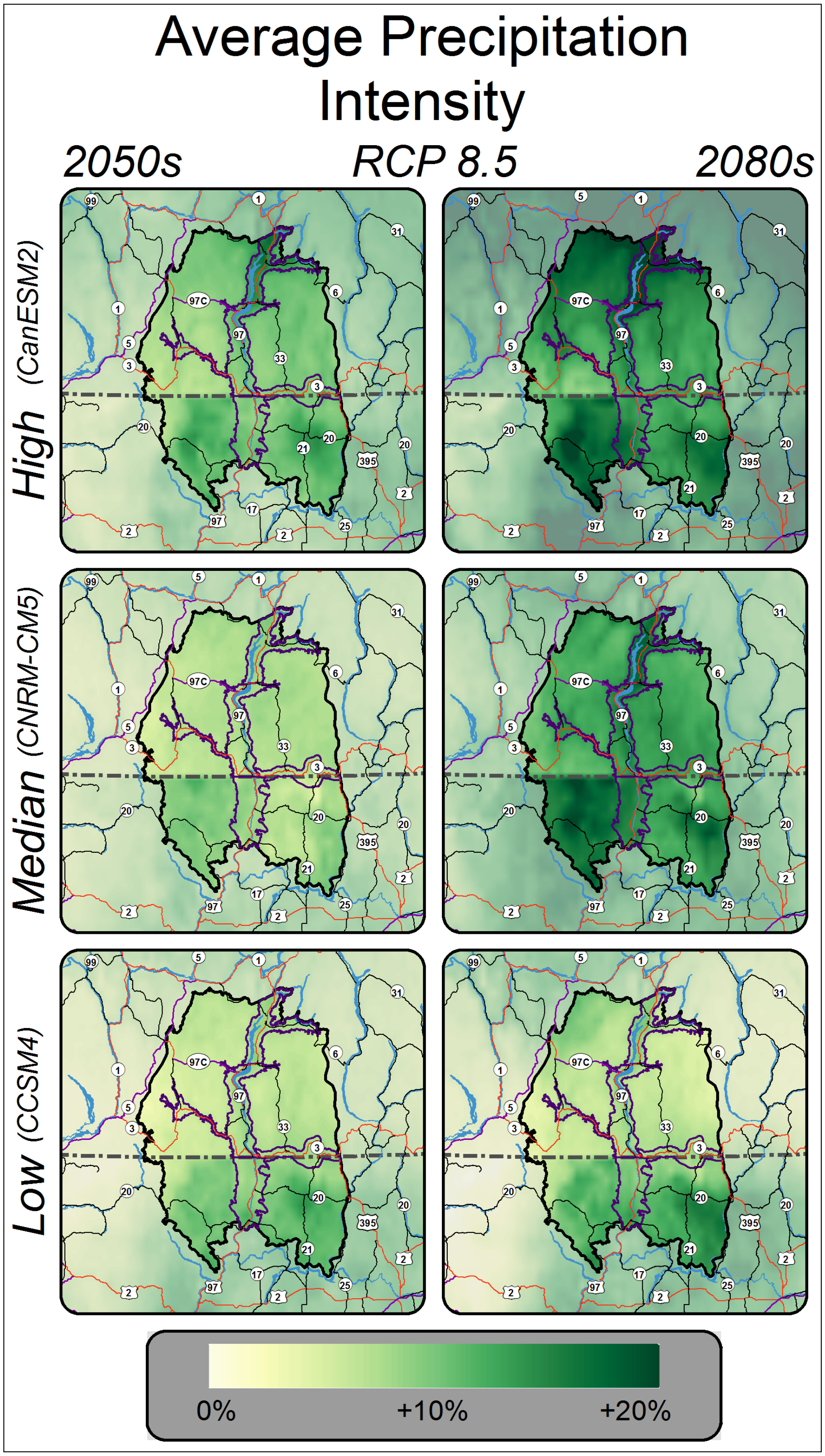
Appendix M.4f. Evapotranspiration, July-September



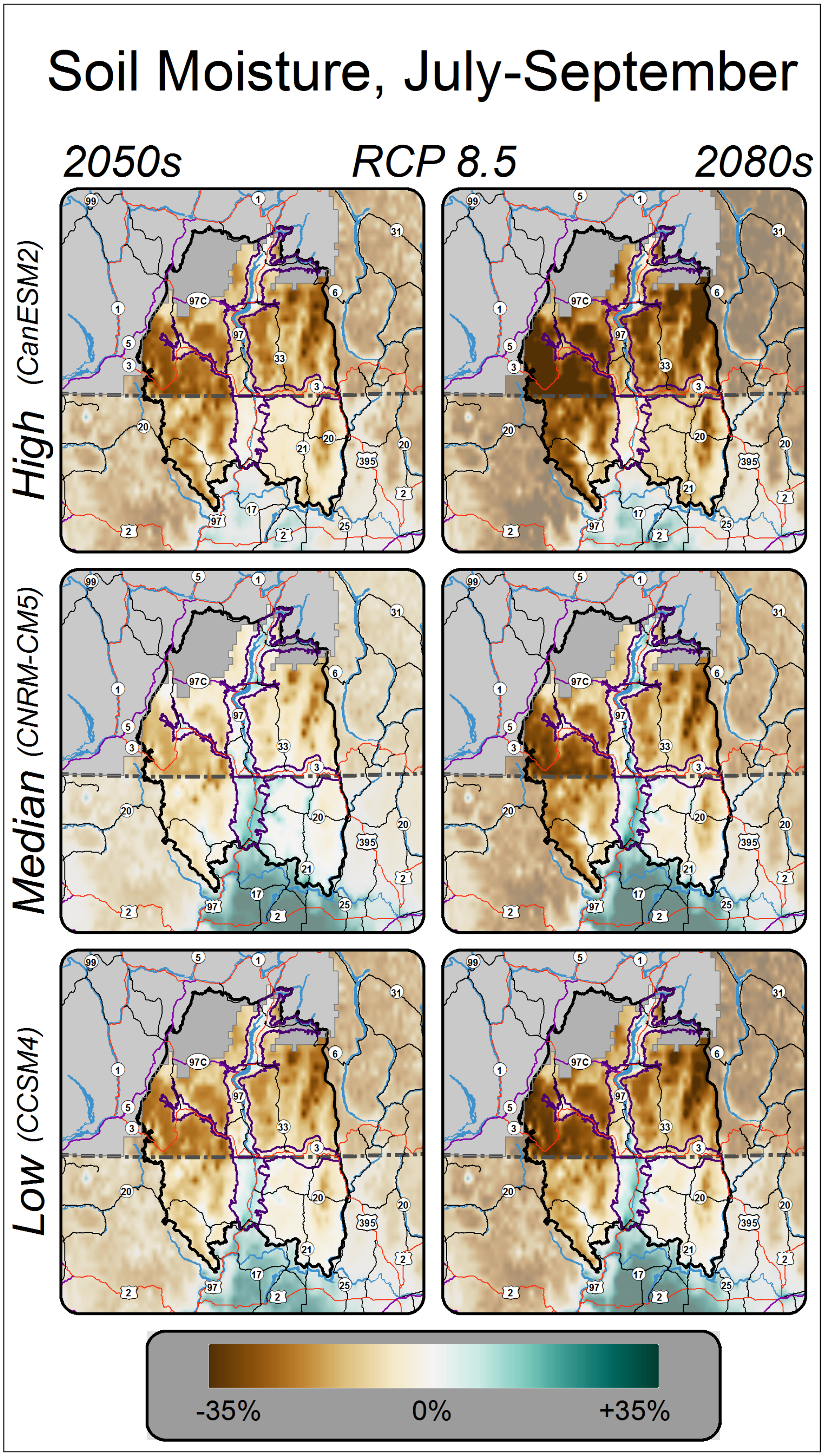
Appendix M.4g. Number of Heavy Precipitation Days



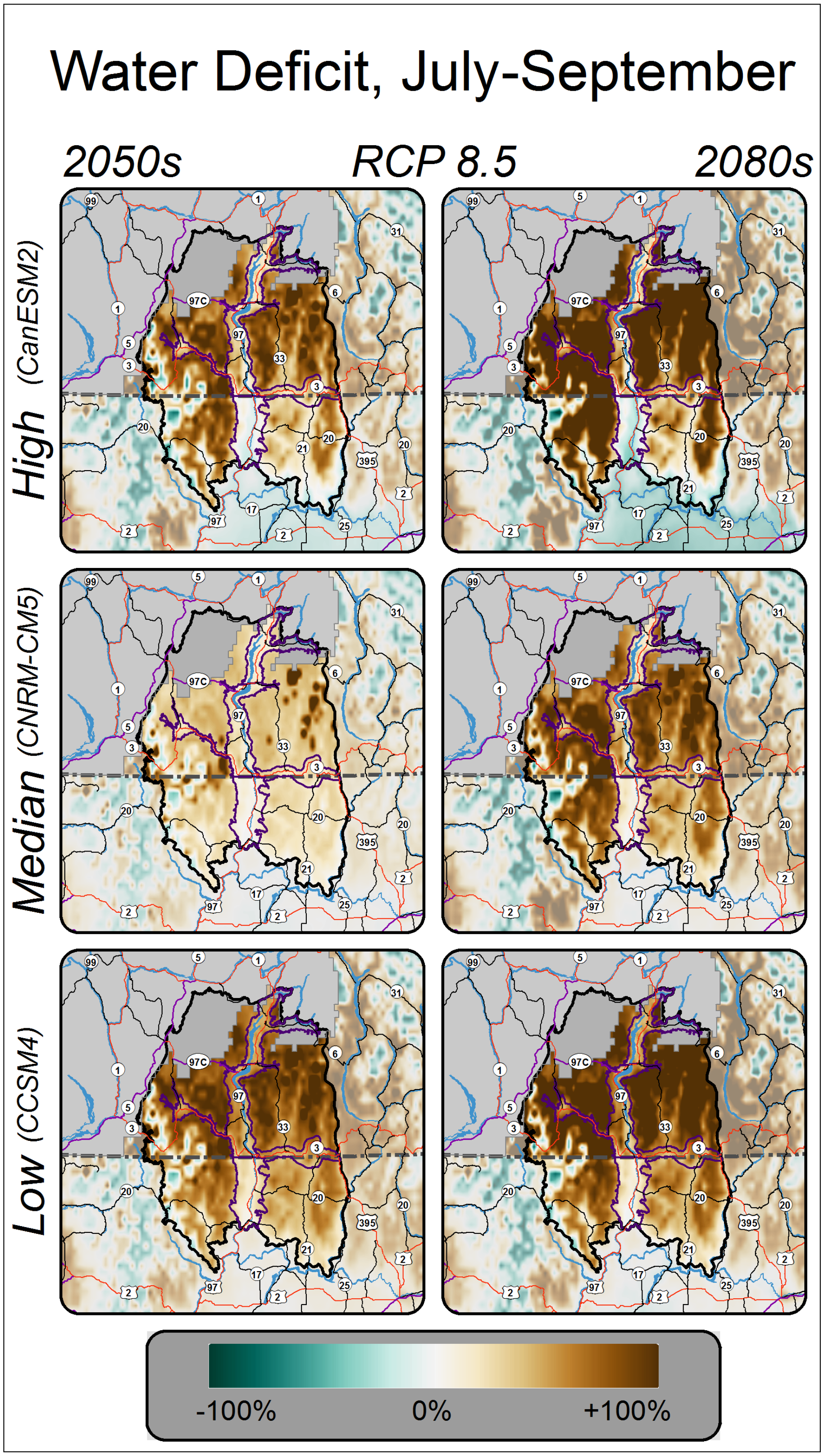
Appendix M.4h. Average Precipitation Intensity



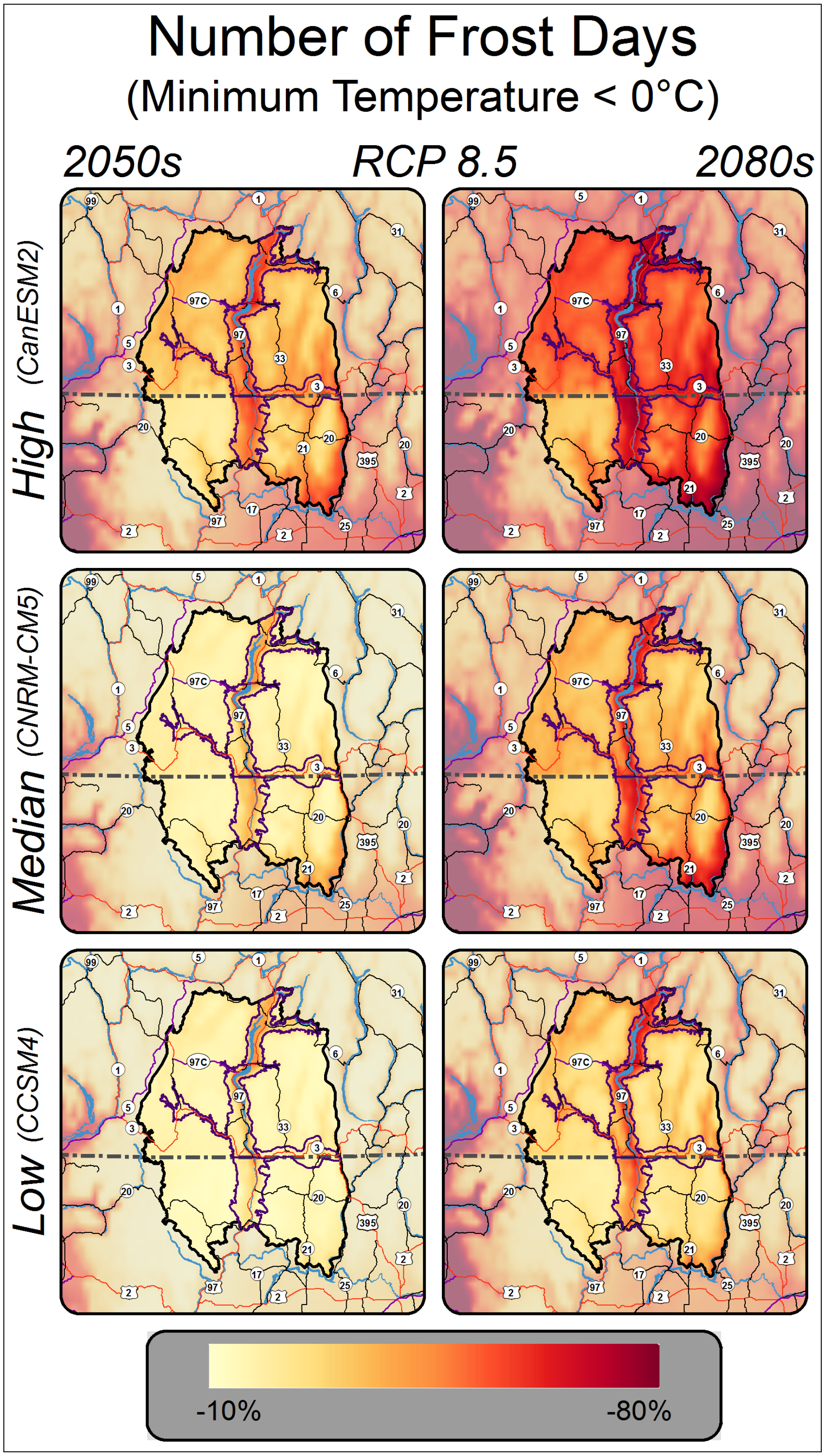
Appendix M.4i. Summer Soil Moisture, July-September



Appendix M.4j. Water Deficit, July-September



Appendix M.4k. Number of Frost Days



Appendix M.4l. Days with High Fire Risk